

CLEO RESULTS ON HEAVY MESON MIXING

HARRY N. NELSON

*Physics Department, University of California, Broida Hall (Bldg. 572), Santa Barbara, CA
93106-9530, USA*

E-mail: hnn@hep.ucsb.edu

We discuss recent CLEO results on $D^0 - \bar{D}^0$ and $B_d^0 - \bar{B}_d^0$ mixing. The principal results are that for the D^0 system, allowing for CP violations, the mixing amplitude $x' < 2.9\%$ (95% C.L.), and for the B_d^0 system, $\chi = 0.198 \pm 0.013 \pm 0.014$. We make projections for future sensitivity to $D^0 - \bar{D}^0$ mixing, and to $\sin(2\beta + \gamma)$.

1 Introduction

The $D^0 - \bar{D}^0$ system is unlike other systems that mix, such as $K^0 - \bar{K}^0$, $B_d^0 - \bar{B}_d^0$, and $B_s^0 - \bar{B}_s^0$ in at least two respects: first, the Standard Model contributions are thought to be extremely small, so non-Standard contributions might be obvious; second, $D^0 - \bar{D}^0$ is the only system that consists of up type quarks. New physics that differentiates between up and down type quarks could be revealed by study of $D^0 - \bar{D}^0$. Indeed, there are numerous models, with relevant particles as massive as 100 TeV, that predict large $D^0 - \bar{D}^0$ mixing.¹

We describe recent results from CLEO II.V on $D^0 - \bar{D}^0$ mixing, where we use the sequence $D^{*+} \rightarrow D^0 \pi_s^+$, where the charged pion is ‘slow’ in momentum, followed by the appearance of a $K^+ \pi^-$ final state, and the sequence formed by application of charge conjugations. We also describe results on $B_d^0 - \bar{B}_d^0$ mixing at the $\Upsilon(4s)$. Following the decay of the $\Upsilon(4s)$ to $B_d^0 \bar{B}_d^0$, we tag one B_d^0 with a semileptonic decay, and the other by a partial reconstruction of the exclusive final state $D^{*+} \pi^-$.

2 $D^0 - \bar{D}^0$ Mixing

The final configuration of the CLEO II detector, known as CLEO II.V, took 9.0 fb^{-1} of e^+e^- collisions between 1996 and 1999.

CLEO II.V featured a vertex detector

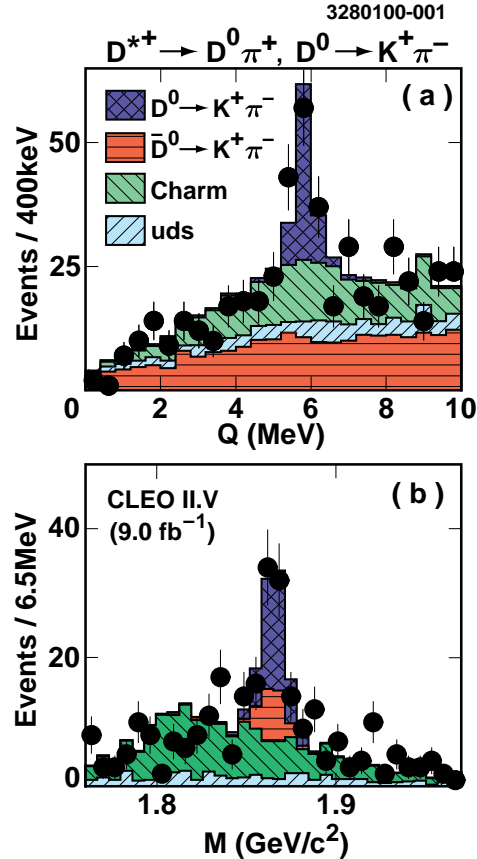


Figure 1. Signal for the ‘wrong sign’ decay $D^0 \rightarrow K^+ \pi^-$, projected onto Q (a) and M (b). The fit for the signal and various backgrounds are given by the hatched and colored histograms.

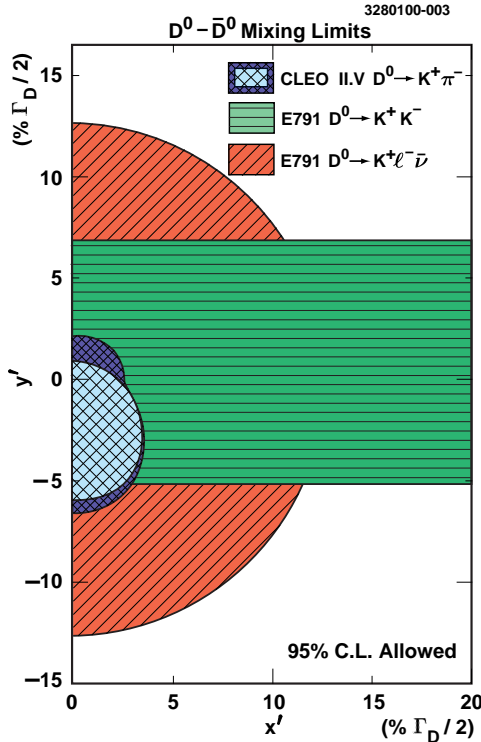


Figure 2. Allowed regions for the mixing amplitudes, x' and y' , at the 95% C.L. Those nearest the origin are from this work, where the inner(outer) region requires(does not require) CP conservation.

(SVX) consisting of three layers of double-sided silicon, and helium as the drift chamber gas. The measurement of z by the SVX narrowed the resolution in Q , the energy released in the $D^{*+} \rightarrow D^0 \pi^+$ decay to $\sigma_Q = 190$ KeV, or about 1/4 that obtained in earlier CLEO work. The use of helium narrowed the resolution in M , the mass reconstructed in $D^0 \rightarrow K^\mp \pi^\pm$, to $\sigma_M = 6.4$ MeV, which is nearly 1/2 that of earlier CLEO work. Both of these resolution improvements are important for detecting the signal of $D^0 \rightarrow K^+ \pi^-$, which is shown in Fig. 1.

The fit in Fig. 1 indicates $44.8^{+9.7}_{-8.7}$ signal events.² The rate of ‘wrong-sign’ decay, relative to ‘right-sign decay’ is $0.332^{+0.063}_{-0.065} \pm 0.040\%$, which is close to $\tan^4 \theta_C$.

We analyze the decay times of the events in the signal region to deduce results on the

$D^0 \rightarrow \bar{D}^0$ mixing amplitudes. The normalized amplitude $x(y)$ describes transitions through off(on)-shell intermediate states. The existence of a direct decay amplitude for $D^0 \rightarrow K^+ \pi^-$ complicates the analysis. The direct decay contributes a purely exponential distribution of decay times. The direct decay amplitude might have a strong phase shift δ relative to the favored decay amplitude, $\bar{D}^0 \rightarrow K^+ \pi^-$, and so the interference of mixing and direct decay contributes decay times according to the distribution $y' t e^{-t}$, where $y' = y \cos \delta - x \sin \delta$. Pure mixing then contributes decay times according to the distribution $(1/4)(x^2 + y^2)t^2 e^{-t}$.

Fits to our data result in the allowed regions in Fig. 2. In our principal results we allow CP violation simultaneously in all three terms of the time evolution: in direct decay, interference, and in mixing.

New physics would most probably appear in the amplitude x . When $\delta = 0$, $x' = x$, and our limit is $x < 2.9\%$ at 95% C.L. At roughly $x \sim 1.0\%$, $D^0 - \bar{D}^0$ mixing would surpass $K^0 - \bar{K}^0$ mixing as the most tight constraint on flavor changing neutral currents.

Our technique is now limited by wrong-sign ‘background’ from the direct decay. We then predict that for future work at the B -factories, this technique will give new sensitivity only as the one-quarter power of the integrated luminosity, and will reach about $x' = 0.7\%$ at 1000 fb^{-1} . In contrast, there are techniques that might be background-free at the ψ'' , and so the scaling with luminosity would go as the one-half power, and hit about $x = 0.1\%$ at 1000 fb^{-1} .

3 $B_d^0 - \bar{B}_d^0$ Mixing

At CESR, the B ’s do not move sufficiently to allow the measurement of decay times. Thus, we are sensitive only to the effect of mixing after integration over the decay time variables, in particular, $\chi = \Gamma(B_d^0 \rightarrow \bar{B}_d^0) / [\Gamma(B_d^0 \rightarrow B_d^0) + \Gamma(B_d^0 \rightarrow \bar{B}_d^0)] \approx (x^2 +$

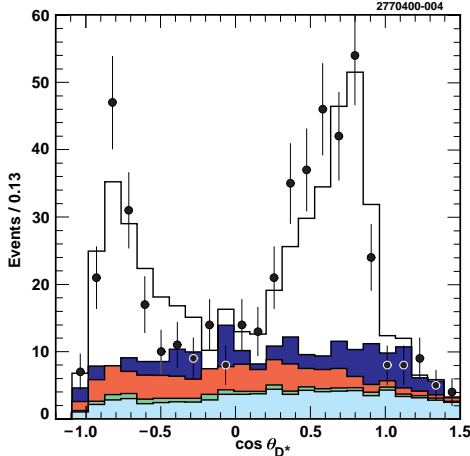


Figure 3. Like sign events, which contain the B mixing signal, as a function of the decay angle of the D^{*+} , $\cos \theta_{D^*}$. The data are the points, and the fit results are full histograms, with backgrounds colored.

$y^2)/2/(1+x^2)$, where x and y were described earlier, but in this case are for the $B_d^0 - \bar{B}_d^0$ system.

We look for the process $\Upsilon(4s) \rightarrow B_d^0 \bar{B}_d^0 \rightarrow \bar{B}_d^0 \bar{B}_d^0$, followed by one $\bar{B}_d^0 \rightarrow X \ell^- \bar{\nu}_\ell$, and the other $\bar{B}_d^0 \rightarrow D^{*+} h_W^-$, and the processes obtained by charge conjugations. The hadron from the W^- , h_W^- , can be either a π^- or a ρ^- , and is fully reconstructed. We reconstruct only the slow pion from $D^{*+} \rightarrow D^0 \pi_s^+$; there is sufficient information to reconstruct all of the decay kinematics with zero constraints.³

The complete CLEO-II data set of 9.1 fb^{-1} taken on the $\Upsilon(4s)$ resonance is used to measure the mixing signal, and 4.4 fb^{-1} taken off-resonance is used to estimate various backgrounds. We observe 458 mixed or ‘like sign’ events ($\ell^\pm h_W^\pm$), shown in Fig. 3, and 1524 unmixed or ‘unlike sign’ events ($\ell^\pm h_W^\mp$).⁴

After correction, we find $\chi = 0.198 \pm 0.013 \pm 0.014$. The principal contributions to the systematic error come from cases where the $\bar{B}_d^0 \rightarrow D^{*+} h_W^-$ decay is a mis-tagged B_d^0 decay (0.009), charged B background (0.007), and uncertainty over two body background (0.006).

If we assume that $|y| \ll x$, as is theoretically expected, we can conclude that $\Delta m = 0.523 \pm 0.029 \pm 0.031 \text{ ps}^{-1}$. Comparison of the charge states of the like sign events allows us to restrict CP violation in B_d^0 state mixing by $|\text{Re}(\epsilon_B)| < 3.4\%$, 95% C.L.

At an accelerator where the B decay times can be measured, the events used here to measure mixing can be used to measure $\sin(2\beta + \gamma)$.⁵ The work in Ref. 5 omitted a form factor suppression in the path through Cabibbo-suppressed decay, and so resulted in an optimistic projection. Using the results here, and with improvements expected at the B -factories from better tagging and use of decay time dependence, we can project that an error on $\sin(2\beta + \gamma)$ of about 1/3 can be reached with 200 fb^{-1} .

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